Preface

The NREL Institutional Plan FY 1997 – FY 2002 pulls together into one document a summary of results of NREL's complete planning processes: strategic planning, operational planning, setting of performance measures, and budgeting. These processes occur at all levels of the Laboratory, including the Laboratory corporate level, the center or organizational level, the program level, the team level, and the individual contributor level.

The Institutional Plan is intended first of all for our major customer, the U.S. Department of Energy (DOE). Therefore, this document describes future directions at the corporate Laboratory level and at the major DOE program level, along with key administrative functions, but does not include specific center-, team-, and individual-level plans.

The Institutional Plan also provides an overview of the Laboratory and its future directions for other major NREL stakeholders, including other national laboratories, industry and business partners, universities, other government agencies, and the public. Lastly, the Institutional Plan describes the linkage of NREL's planned activities to national goals and DOE's strategic directions.

This Institutional Plan differs from earlier plans in being offered in two volumes:

Copies of the *NREL Institutional Plan FY 1997 – FY 2002* (Volume I, Volume II, or both) can be obtained through NREL's External Relations Office. Comments on the Plan may be addressed to:

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Table of Contents for Scientific and Technical Programs

Assistant Secretary for Energy Efficiency and Renewable Energy (DOE/EE)

Office of Utility Technologies

The Office of Utility Technologies (OUT) within the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EE), supports research and development (R&D) related to the utility sector. The specific goals of the office are to improve the cost-effectiveness of renewable energy technologies for electric power generation; to accelerate R&D of new transmission, distribution, and storage technologies; to promote integrated resource planning techniques; and to expand the market for renewable energy technologies that produce electric power.

DOE/EE OFFICE OF UTILITY TECHNOLOGIES

NREL Funding by Fiscal Year

($ in millions--Budget Authority)

	Fiscal Year*				
Office of Utility Technologies	1995	1996	1997	1998	1999
Operating					
Electric Field Effects (AK04)	$0.1	$0.3	$0.3	$0.3	$0.3
Reliability Research (AK05)	0.0	0.0	0.0	0.0	0.0
Systems & Materials Research (AK06)	1.0	1.0	1.0	1.0	1.0
Battery Storage & Development (AL05)	0.1	0.0	0.0	0.0	0.0
Geothermal Technology Development (AM10)	1.2	1.3	1.3	1.3	1.4
Hydrogen (AR) (see below under EB42)	2.8	3.8	0.0	0.0	0.0
Photovoltaic Energy Systems (EB22)	48.0	39.1	39.9	41.1	42.3
Solar Thermal Energy Systems (EB2311)	4.3	3.5	3.5	3.6	3.7
Biofuels Energy Systems (Biomass Power) (EB2411)	3.6	3.3	3.3	3.4	3.5
Wind Energy Systems (EB25)	35.1	22.6	24.3	25.0	25.8
Solar International Programs (EB27)	2.5	0.4	0.4	0.4	0.4
Solar Technology Transfer (EB28)	13.1	2.4	2.4	2.5	2.5
Solar Program Support (EB29)	1.2	0.1	0.1	0.1	0.1
Resource Assessment (EB35)	3.2	1.7	0.0	0.0	0.0
Hydrogen Research R&D (EB42) (see above under AR)	0.0	0.0	3.0	3.1	3.2
Integrated Resource Planning (EK60)	1.6	0.0	0.0	0.0	0.0
Subtotal Operating	$117.9	$79.3	$79.3	$81.7	$84.2
Capital Equipment					
Geothermal (35AM)	0.2	0.1	0.1	0.1	0.1
Hydrogen (35AR)	0.2	0.0	0.0	0.0	0.0
Solar Energy (35EB)	5.2	3.0	3.0	3.1	3.2
Solar Energy Research Facility (Misc.)	0.4	0.0	0.0	0.0	0.0
Total Utility Technologies	$123.5	$82.4	$82.4	$84.9	$87.5
Percent of Total Laboratory Funding	49%	45%	45%	45%	45%

*FY 1995 and FY 1996 are actuals; FY 1997 is best estimate; FY 1998 and beyond are generally projected based on 3% inflation.

Photovoltaics

The potential market for photovoltaics (PV)—the direct conversion of sunlight into electricity—is staggering. Since 1987 the worldwide demand for photovoltaics has grown from 29 megawatts (MW) per year to over 80 MW per year, an increase of over 250%. During the same period, U.S. PV companies have increased their module shipments by 400% and have become the world market leader with a share of over 40%. Currently, the U.S. PV industry does more than $350 million of business per year. A study by the Utility Photovoltaic Group suggests that, as system costs drop to $3 per watt, demand may rise to greater than 9000 MW for domestic applications alone.

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An additional benefit of PV for the U.S. economy derives from the fact that much of the U.S. production (currently about 70%) is exported, which helps restore the balance of trade. This export market taps into the huge potential associated with some 2 billion people in remote and developing areas around the world still lacking the benefits of electricity.

An array of cadmium telluride solar modules manufactured by Solar Cells, Inc, is now transferring up to 10 kW of electricity at peak hours of sunlight into the Toledo Edison power network in Ohio. (Photo - Solar Cells, Inc.)

The list of actual and potential PV applications could include nearly anything that requires electric power. Near an electrical grid, PV applications include grid-connected building systems, grid-distribution support, utility peaking power, and bulk power applications. Remote from an electrical grid, PV systems can supply electricity for remote water pumping, cathodic protection, remote telecommunications systems, rural lighting and small appliances, and village power.

There are many semiconductor materials and technologies for converting sunlight into electricity. Crystalline silicon is likely to dominate PV markets at least through the year 2000. With its relatively high efficiency, stability, competitive cost, and proven track record, it plays a dominant role in both domestic and international markets. Modules made from crystalline and multicrystalline silicon accounted for about 95% of all the modules sold by U.S. PV manufacturers.

Thin films, typically 200 to 300 times thinner than crystalline silicon cells, are a promising path to low-cost photovoltaics and at least eight U.S. companies are planning or building thin-film PV manufacturing plants. These thin-film materials include amorphous silicon, cadmium telluride, and copper indium diselenide. The development of these materials constitutes a major element in

NREL's program, the Thin-Film PV Partnership Program. Another thin-film material, gallium arsenide, has long been in the laboratory stage, where it has shown very high efficiency at very high cost; cutting-edge science is just beginning to explore how this technology's cost can be reduced.

In November 1996, DOE established the National Center for Photovoltaics (NCPV), located at NREL, to be the focal point for developing technology and disseminating information about PV in the United States. The goal of the NCPV is to build on and link the core set of facilities and expert staff at NREL and Sandia National Laboratories with additional resources in universities, industry and other federal and state programs into a united effort to accelerate the advance of photovoltaics as an industry and energy source. An Operations Office comprised of PV managers at NREL and Sandia will manage the day-to-day activities of the NCPV. The NCPV is further described in Volume I of this Institutional Plan.

Since 1978, NREL has managed and implemented major elements of the federal PV program, focusing on research and development of new PV technologies. NREL manages PV-related R&D activities that include cost-shared, multiyear government-industry partnerships, national team-research efforts, and technology initiatives. Scientists at NREL also support the DOE PV program with fundamental and applied research, device measurements, cell modeling and fabrication, and the characterization of both materials and devices using advanced measurement

New building consolidates PV testing and evaluation

NREL supports the U.S. photovoltaics industry by testing as many as 3500 cells, modules and systems every year. A new 10,000-square-foot laboratory building consolidates many of these test capabilities into a central location for more efficient operation.

Completed in 1995, the expanded test facility allows researchers to evaluate advanced photovoltaic technologies under simulated, accelerated, and prevailing outdoor conditions.

Simulated and accelerated testing is conducted in eight laboratories housed within the new building. A large high-bay test laboratory helps determine how modules perform when exposed to heat, cold, humidity, moisture, and ultraviolet light. Mechanical tests include simulating hail strikes and flexing modules 10,000 times at different angles to test structural strength. Modules also can be tested in high-voltage conditions to evaluate electrical insulation and verify that moisture will not cause corrosion, ground faults, or electrical safety hazards.

Outdoors, complete photovoltaic systems can be connected to the local utility grid to investigate interconnection issues such as harmonics and verify electrical output. More than 100 modules and six systems are currently being tested. NREL also monitors two 6-kilowatt systems mounted on the nearby Solar Energy Research Facility.

equipment and techniques. NREL researchers conduct simulated and actual outdoor tests on cells, modules, and arrays for industry and universities. They also compile solar radiation data, critically important to solar system designers and manufacturers.

Thin-film PV achieves record efficiencies

With energy costs now averaging about 22¢ per kilowatt-hour, today's silicon-based photovoltaic systems are cost competitive for many remote power applications. But further cost reductions are required for photovoltaics to achieve widespread use as bulk power generators. NREL researchers are investigating a variety of approaches toward this goal, including the use of thin films of highly efficient semiconductor materials applied to inexpensive substrates.

In 1996, NREL scientists achieved a world-record 17.7% efficiency in converting sunlight to electricity with a photovoltaic cell made of thin-film copper indium gallium diselenide. The Laboratory's state-of-the-art equipment played a major role in this achievement by revealing basic material properties and providing valuable information on the interaction of various cell layers.

Copper indium diselenide and its alloys are among the most promising thin-film photovoltaic materials because they readily absorb light and have few electronic defects. However, the complex composition of these advanced semiconductors has made it difficult to control and optimize their photo-electronic properties. By combining these insights with advanced, automated vacuum-processing techniques, NREL researchers tailored the material properties for its record-breaking cell.

NREL will continue to carry out a program balanced between basic research and technology applications with three major elements—research and development, technology development, and systems engineering and applications. In the area of research and development, scientists conduct basic and applied research on promising new materials, processes, devices, and production techniques.

In concert with industry, NREL researchers move ideas from the drawing board to the laboratory bench-scale and prototype development. Technology development involves translating laboratory innovations in materials, processing, and system operation. Through an industry-directed research partnership, Photovoltaic Manufacturing Technology, NREL helps advance PV manufacturing technologies, reduces module production cost, increases module performance, improves balance-of-system components, and expands U.S. production capacities. The third area, systems engineering and applications, includes the measurement and documentation of performance of PV systems and dissemination of information on PV characteristics. Here also, NREL conducts projects that demonstrate the performance and value of PV systems in applications for key markets.

Another important aspect of NREL's program includes subcontracting about half of its program to industry and universities. Cost-shared, multiyear subcontracts with industrial partners have proved to be an effective means for the continuing increase in PV performance and reduction in PV system cost. NREL funds about 60 universities, typically in joint research and development activities with industry. In addition to NREL's subcontracted projects, the increased interest by NREL researchers and industry in cooperative research and development agreements for collaborative work has resulted in NREL researchers working on some company-specific technology development activities.

Wind Energy

Wind energy has proven to be the most cost-competitive and most used solar energy technology for the bulk power market. Of the approximately 5000 MW of wind-generating capacity interconnected with utilities worldwide at the end of 1996, more than 1600 MW are installed in the United States, which has about 16,000 machines. In addition, more than 30,000 smaller electrical systems (0.5 to 10 kilowatts [kW]) are used in remote and stand-alone applications.

While installations in the early 1980s were plagued with reliability and performance problems, the industry has improved the technology to the point that today's utility-interconnected machines produce power at costs of about $0.05/kilowatt-hour (kWh) (at a 13-mph site), rivaling some nonrenewable sources.

NREL researchers work on a variable-speed generator experiment at the National Wind Technology Center. (Photo - Warren Gretz, NREL)

Certification testing is another way that NREL assists the U.S. wind industry. An NREL engineer measures noise emissions from an advanced wind turbine at the National Wind Technology Center. (Photo - Warren Gretz, NREL)

NREL develops, improves, and demonstrates the viability of wind technology for electricity generation and facilitates its deployment throughout the world. NREL helps DOE implement the federal wind energy development program. NREL will help industry improve its competitive position, lead the development of advanced wind turbines, upgrade the applied research base, and help utilities deploy the technology.

The Laboratory will continue applied research in aerodynamics, structural dynamics and fatigue, power systems, and advanced concepts. This research is vital to achieve cost goals for wind technology by 2000. Applied research provides the technical underpinnings for advanced machine technology and also provides information and data required to address near-term industry problems. Problems associated with drivetrains, variable-speed operation, aerodynamic control systems, teetered-rotor performance, and system control must be addressed. During the next 5 years NREL will perform the following R&D tasks:

Our focus is now targeted to meet a $0.025/kWh goal by 2000, at sites with good wind resource and favorable financing.

- Test variable-speed concepts
- Develop advanced structural analysis codes
- Develop a high-flexibility blade structure
- Design fatigue-tolerant rotors
- Optimize codes for horizontal-axis wind turbine rotors
- Design structurally tailored rotors.

To support industry efforts, NREL plans to design, fabricate, and field-test advanced wind turbines. Current machine designs, generating electricity costing about $0.05/kWh, are competitive in selected applications. However, our focus is now targeted to meet a $0.025/kWh goal by 2000, at sites with good wind resource and favorable financing. The advanced industry designs currently being developed, both with private funding and under the DOE-supported Turbine Development Program, will provide U.S. utilities with near-term alternatives to foreign machines.

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Ultimately, wind energy may have to compete with gas-fired combustion turbines, which dominate most new generation additions in the United States where the majority of the good wind resource is located. Midwest sites have less energetic wind regimes than those currently being exploited in California, implying that increases of up to 50% in energy production efficiency will be needed. The mid-term goal of the program is to provide next-generation, utility-grade machines for 2000 that meet the needs of the utility industry by incorporating the best current technological improvements.

The DOE Federal Wind Energy Program is working as a partner with utilities and industry to achieve multiregional U.S. market penetration of wind systems and to establish the United States as the world leader in the development and use of advanced wind turbine technology. By involving industry in the planning process, the program can emphasize industry-driven priorities, especially in the near term. For example, the program has extensive interaction with utility/industry players through its annual meetings with the American Wind Energy Association R&D Committee. In addition, the program consults regularly with interested utilities and their research organization, the Electric Power Research Institute (EPRI). Finally, the program actively participates in International Energy Agency activities to stay abreast of international R&D programs and developments in the international marketplace.

Several cost-shared cooperative projects with the wind industry are planned. The Turbine Development Program assisted industry efforts to incorporate advanced wind turbine technology into commercial machines for the 1995 timeframe, and will provide the next generation of utility-grade wind turbines by the turn of the century. The DOE/EPRI Utility Verification Program deploys and evaluates commercial/prototype wind turbines in typical utility-operating environments. This technology demonstration is a necessary bridge from current advanced turbine development activities to a time when utilities will begin large-scale purchases of wind turbines.

DOE has established the National Wind Technology Center at NREL to provide the United States with a world-class wind energy R&D center.

DOE has established the National Wind Technology Center at NREL to provide the United States with a world-class wind energy R&D center. Wind application assistance is being provided to the potential users of wind systems to ensure appropriate application of the technology and to help develop and test new applications. A small turbine development activity will be undertaken to help industry develop a new generation of small (less than 50 kW) wind turbines.

Biomass Power

Biomass is a major renewable generation source today. In the United States, grid-connected biomass electric plants can produce nearly 7 gigawatts (GW), which is 1% of all generating capacity and about 8% of nonutility generation capability. Many of these plants produce both heat and power for the industrial sector, mainly in the wood products industry using process residues.

Demonstrating a more efficient way to generate electricity with the by-product of milling sugarcane is one way for U.S. technology to tap into worldwide power markets. NREL and DOE managers examine sugarcane waste in Hawaii. (Photo - Warren Gretz, NREL)

Another strong application for biomass power is stand-alone power generation. These plants are typically fueled with municipal solid waste and residues from smaller or seasonal industries such as orchards, food processing, and building construction and demolition. Stand-alone power producers often play an integral role in the management of residue and waste flows in a region, accepting clean materials that otherwise would be landfilled and thereby contributing to the sustainability of communities.

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The U.S. biomass power industry is located primarily in the Northeast, Southeast, and along the West Coast, representing an investment base of $15 billion and supporting about 66,000 jobs. For stand-alone facilities that produce only electricity, net power efficiency in the existing biomass power industry is 20% to 25%, using steam-cycle technology with conventional furnace and fluidized-bed combustors. While this efficiency is lower than modern coal- and gas-fired units, recent projects have demonstrated the potential to improve the reliability and efficiency of existing biomass systems.

The ready availability of biomass wastes, coupled with favorable power contracts, fueled the rapid development of the industry up until the mid-1980s. Expiration of these early contracts, increased competition for biomass resources, and lower prices being paid for biomass-generated electricity have combined to put significant pressure on the power industry to close or revitalize the less-efficient operations.

Biomass resources can be expanded through development of renewable energy crops and can bring added value in coproducts, local environmental preservation (soil and water conservation and wildlife biodiversity), and global climate change insurance (because biomass sequesters carbon while growing). The potential exists for biomass power to grow to an industry of 30,000-MW capacity, employing 150,000 persons in mainly rural areas and producing 150-200 billion kWh of electricity by 2020. The major factors that may facilitate the greater use of biomass resources include:

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- Aging chemical recovery boilers in the pulp and paper industry may be reconfigured with biomass integrated gasification combined-cycle systems, where biomass can be uniquely used as fuel in combined heat and power applications.

- The cofiring and repowering of coal facilities in regions where biomass resources are abundant provides another route to capacity growth at lower cost per unit of capacity. Cofiring may pave the way for other advanced technologies into commercial markets.

- Biomass power/natural gas hybrid systems may offer a reduced risk in electricity bids by independent system operators.

- Developing a local bioenergy sector and providing reliable electricity will provide rural economic development benefits and help sustain biomass industry growth domestically and in developing countries. Furthermore, expanded use of biomass in developing countries will decrease the need for subsidies to the power and fuels sectors while also reducing their reliance on imported petroleum products.

NREL provides management and technical guidance to the National Biomass Power Program.

In 1991, DOE formed the National Biomass Power Program to help establish a sustainable option to contribute to the 600 GW of new electric generating capacity projected to be needed globally over the next 10 years. The Biomass Power Program includes such activities as: working with the biomass power industry to overcome problems in using some forms of biomass in existing boilers; evaluating and developing advanced technologies such as gasification and pyrolysis; developing clean-up technology for high-temperature biogas; sponsoring cost-shared feasibility studies with industry; and supporting cost-shared, small- and large-system demonstrations.

In a continuing effort to increase its effectiveness, the Biomass Power Program is working cooperatively with a number of other programs and federal agencies. For example, DOE is working with the U.S. Department of Agriculture on the Biomass Power for Rural Development Initiative to help private industry demonstrate and deploy cost-competitive renewable biomass power systems that also stimulate rural economic development.

NREL conducts thermochemical conversion research, manages program activities, and monitors demonstration projects such as the McNeil Generating station in Vermont, which generates electricity from wood. (Photo - Burlington Electric Department)

Also, the Advanced Turbine Systems Program, a joint effort between industry and DOE's Offices of Fossil Energy and Energy Efficiency and Renewable Energy, strives to develop higher efficiency (gas-fired) turbines for industrial and utility applications using fuels derived from coal and biomass, as well as natural gas. The Biomass Power Program also accesses other programs within EE, including the Biofuels Feedstock Development Program for short-rotation woody crops and herbaceous energy crops.

NREL provides management and technical guidance to the national program. This research center is responsible for day-to-day management of biomass power research and development activities and for meeting the technical goals of the national program. NREL manages program activities, subcontracted work, and in-house research projects in areas assigned by the director of EE's Solar Thermal and Biomass Power Division. NREL also conducts thermochemical conversion research, including research to improve advanced conversion technologies for gas turbines, demonstrate gasifier/fuel cell systems, and improve combustion systems.

Lastly, NREL assists with systems development efforts, including technoeconomic assessments, biomass resource assessment efforts, prefeasibility studies for integrated feedstock/conversion projects, support of demonstration projects, and support of commercial projects. Program efforts will concentrate on management and support of demonstration projects in Hawaii and Vermont, and commercial projects under the auspices of the Biomass Power for Rural Development Program.

Solar Thermal Electric

Solar thermal electric technologies concentrate the sun's thermal energy and convert this energy to electricity through a variety of thermodynamic cycles, and offer a number of attractive features as a source of electricity. Power systems are highly modular, and can be designed for applications ranging from 20-kWe remote loads to 200-MWe grid-connected plants. Using thermal conversion cycles allows incorporation of low-cost energy storage and/or fossil fuel backups, which can provide complete dispatchability of the plant with high reliability. The power systems have minimal environmental impacts, can be designed for little or no water use, and because of their high efficiency (up to 29% conversion of sunlight to electricity), land requirements are minimized.

NREL develops stretch membrane heliostats for solar thermal electric systems such as this Cummins/Stirling engine. (Photo - Warren Gretz, NREL)

In 1995 NREL joined with Sandia National Laboratories to create . . . a single, unified "virtual" laboratory called SunLab.

Three main solar thermal electric technologies currently being pursued by DOE and the U.S. industry are troughs, central receivers (power towers), and dish/engine. Trough technologies are in the early stages of commercialization, with 354 MW of currently installed capacity in Southern California. Power towers (also called central receivers) are an emerging technology that is currently being demonstrated by the Solar Two pilot plant in Barstow, California.

Although both troughs and power towers are intended for large-scale, grid-connected applications, dish/engine technologies are aimed at smaller installations and remote applications. Dish/engine systems are designed for unattended operation, and can be installed in modules of 20 kW and larger. Like power towers, dish/engine designs are in a demonstration and development phase, with commercial sales projected toward the end of the decade.

In 1995 NREL joined with Sandia National Laboratories to create a partnership unique to the national laboratory system: a single, unified "virtual" laboratory called SunLab. SunLab combines

NREL's and Sandia's expertise and experience to enhance research efforts, help manufacturers develop improved solar thermal systems, and help companies penetrate growing domestic and international energy markets. Under SunLab, the solar thermal programs at the two laboratories work together as a single business unit, directed by a single team of people representing both laboratories. SunLab has resulted in increased productivity in R&D, savings in management and administration costs, and improved responsiveness to industry and DOE Headquarters needs.

NREL fires up hybrids with the Kokhala concept

NREL's emphasis in the Solar Thermal Electric Program is on developing creative solutions to improve the performance and cost of solar thermal technology, and working with industry to transform ideas into commercial products. An example of translating this creativity into results is found in the "Kokhala" power tower design developed at NREL. The name "Kokhala" comes form a Hopi Indian word meaning "heat from fire or sun."

The Kokhala concept embodies this idea by providing energy to a combined-cycle power plant from a combination of solar heat and natural gas. The hybrid fuel source allows the plant to be totally dispatchable regardless of insolation, and the high efficiency of the combined cycle allows a reduction of the cost of solar electricity by nearly a factor of two. In addition to these advantages, the Kokhala concept has a much lower commercialization risk than earlier power tower designs, and has resulted in significant interest by U.S. industry.

NREL's technical activities in this program are broad. NREL supports industry in the test and evaluation of the Solar Two project as well as joint ventures for the development of dish/engine technologies. A manufacturing initiative, aimed at fostering more rapid commercialization by reducing the manufacturing cost of solar components, has resulted in an estimated 25% reduction in the cost of heliostats for power tower systems.

The Laboratory is developing and testing advanced optical materials that hold promise for substantial reductions in the cost of advanced solar concentrators, as well as designing new hybrid receiver concepts for dish/engine systems that will allow these technologies to extend operating hours through the use of fossil fuels.

NREL's high-flux solar furnace is a national user facility, and offers opportunities for industry and researchers to test advanced solar processes in a unique experimental facility. Finally, NREL's analysis capabilities extend from the use of detailed computer codes for the design of new solar components, to the ability to predict the thermodynamic and economic performance of solar plants at sites worldwide.

Solar Buildings

The Solar Buildings Program was established by the EE's Office of Utility Technologies in FY 1997 for the purpose of developing solar technologies that provide cost-competitive energy for buildings. Such technologies include solar heating systems and PV integrated into buildings; these technologies provide hot water, electricity, space heating or cooling, and process heat for residential, commercial, or industrial applications.

One of the primary areas for NREL research in solar buildings is domestic solar hot water and industrial process heat. To date, an estimated 1 million solar hot water systems have been installed within the United States, most of which were installed prior to the expiration of federal tax credits in 1986. The current residential hot water heater replacement market represents a market potential of 27 million systems within the United States; while the potential exists for an estimated 700,000 additional systems per year from new home construction in areas suitable for solar.

In addition, the industrial and commercial markets for high-temperature water and air applications are also significant.

New solar collector delivers lower energy costs

An innovative solar collector developed by NREL and Conserval Inc. of Buffalo, New York, is now slashing utility bills for several Fortune 500 companies. Marketed under the name Solarwall®, the innovative collector uses solar energy to preheat building ventilation air with an average daily efficiency of more than 70%.

Unlike conventional collectors, Solarwall doesn't require a glass cover. Sunlight heats a wall panel made of perforated metal, and the adjacent outside air is warmed by 30° to 40° F. Ventilation system fans draw the heated air through the perforations and deliver it to the building. Heat that would otherwise be lost to the wind is captured by suction through the perforations.

The latest Solarwall was installed on a south-facing wall of the Federal Express building in Littleton, Colorado, where it will reduce the use of natural gas by more than 2 billion Btu per year—an annual savings of almost $12,000. At this level of performance, the payback period for the 5000-square-foot collector is about 5 years.

NREL's computer design software assisted Conserval with the Federal Express installation. Solarwall collectors have also been installed on buildings owned by General Motors Corporation and Ford Motor Company. This technology recently captured awards from both *Popular Science* and *R&D* magazines as one of the year's top scientific innovations.

Applications include industrial process heat, commercial space heating and cooling, and ventilation air preheat for commercial buildings.

However, significant cost reductions are necessary if solar heating technologies are to compete economically with today's low energy prices in the United States. International markets, where energy costs are typically greater than within the United States and acceptance of renewable technologies is higher, may represent a significant potential for U.S. manufacturers of solar technologies.

Another primary area for NREL research in solar buildings is building-integrated photovoltaics (BIPV). Numerous advantages may result from the use of photovoltaics in building-integrated applications. BIPV systems can replace existing building components such as wall glazings, roof materials, and windows with photovoltaic components that can generate electricity. Such dual-purpose construction helps to reduce the cost of the photovoltaic systems, especially when coupled with other energy-efficient building concepts such as pv-integrated electrochromic "smart windows."

NREL and Sandia work closely with industry to identify and develop technology improvements, reduce manufacturing costs, monitor system performance, and identify potential new markets.

EE's Solar Buildings Program is managed using a team consisting of representatives from EE's Solar Thermal and PV programs, the NREL Technology Manager, and representatives from the Solar Energy Industries Association. Additional team members representing key customer groups are anticipated as the program evolves. The management team makes joint decisions establishing near- and long-term program directions and priorities.

NREL's role within EE's Solar Buildings Program focuses primarily on technology development and support to industry. NREL, together with Sandia National Laboratories, supports the development and testing of numerous technologies for buildings applications, including flat-plate collectors for residential and commercial hot water, transpired hot air collectors for ventilation preheat for commercial buildings (see box on previous page), and concentrating and evacuated-tube collectors for industrial-grade hot water and solar absorption cooling applications.

NREL and Sandia work closely with industry to identify and develop technology improvements, reduce manufacturing costs, monitor system performance, and identify potential new markets. In addition, the laboratories conduct research and development activities for the purpose of generating "next-generation" technologies for buildings applications, resulting in the expansion of domestic and international markets.

The Solar Buildings Program plans to conduct several customer workshops early in FY 1997. The purpose of the planning workshops, which will include members from the housing, utility, industrial, and financial communities, will be to solicit objective feedback on technical and nontechnical barriers to achieving market success of solar building technologies. These workshops will help in the development of application-specific commercialization “roadmaps," a cooperative effort by DOE, the solar industry, and key customers. These roadmaps will guide the program in its pursuit of displacing a quad of energy by the year 2020.

Hydrogen

Hydrogen is currently used in the metallurgy, cosmetics, food processing, and semiconductor industries, and its role in chemical processing, petroleum refining, and fertilizer production is critical. Hydrogen has the potential for widespread use as a transportation fuel and for energy transmission and storage if production costs can be lowered and efficient storage systems are developed.

This outdoor experimental facility produces hydrogen from sunlight using photobiological techniques. (Photo - Mike Linenberger, NREL)

The main areas for technical development are hydrogen production from renewable sources, hydrogen storage and transport, and infrastructure changes. Currently, most hydrogen is produced by steam reforming of natural gas. For high-purity uses, hydrogen is also produced by electrolysis of water. Research at NREL focuses on production of hydrogen using photobiological and photoelectrochemical systems. Biomass can also be used to produce hydrogen through pyrolysis and gasification processes.

The main challenge for hydrogen production from renewables is to reduce the cost. For hydrogen storage and transport, technical challenges include the ability to safely and economically store hydrogen for stationary and mobile applications.

The widespread use of hydrogen produced from renewables would be a major step toward achieving a sustainable energy economy for several reasons. Hydrogen, when used in a fuel cell, produces only water. When used in a combustion process, water and small amounts of nitrogen oxides are the only products. Also, the use of hydrogen for fuel-cell-powered electric vehicles could increase the energy efficiency by a factor of two to three compared to gasoline-fueled engine vehicles.

NREL strives to develop economically viable hydrogen systems for energy-related applications. NREL's role is primarily field technical management of DOE's R&D program, including management of inhouse research. NREL conducts basic and applied research on innovative new materials and devices for cost-effective methods of generating and storing hydrogen. The Laboratory disseminates program information to laboratories, universities, other federal agencies, and private industry. NREL has management responsibilities for the Secretary's Hydrogen Technical Advisory Panel.

During the next five years NREL plans to conduct an R&D program to achieve 15% photoconversion efficiency for renewable hydrogen production. Scale up of the biomass pyrolysis system is expected to result in a cost of hydrogen that is competitive with large-scale steam methane reforming. Hydrogen sensors based on fiber optic technology are expected to be commercialized through a CRADA. Development of practical storage systems is planned for both mobile and stationary applications. NREL will conduct systems analysis and seek to initiate CRADAs to encourage industry to perform large-scale testing of newly developed technologies.

During the next five years NREL plans to conduct an R&D program to achieve 15% photoconversion efficiency for renewable hydrogen production.

Geothermal Energy

NREL is actively involved in the Geothermal Energy Conversion Project, which is part of the Geothermal Energy Program conducted by the EE's Office of Geothermal Technologies. The objective of the Geothermal Energy Conversion Project is to promote the economical production of electricity from geothermal resources by increasing brine utilization efficiencies, decreasing capital and operating costs, and assuring the environmental compatabilities of geothermal energy conversion technologies.

The Geothermal Energy Conversion Project works with industry to establish a technology base that will enable industry to exploit the vast and diverse geothermal resource. The long-term approach is to develop advanced power-cycle technologies to increase power generation efficiencies and to develop new materials capable of withstanding high temperatures, pressures, and corrosive environments. The scientific approach is directed toward areas where improvements can reduce the costs of hydrothermal power to a level competitive with conventional energy sources.

The Geothermal Energy Conversion Project works with industry to establish a technology base that will enable industry to exploit the vast and diverse geothermal resource.

Improvements are sought in capital costs, operation costs, and plant reliability in both existing and future geothermal plants. Wherever practical, research is conducted cooperatively with the geothermal industry to ensure that the technical advances meet industry needs and accelerate the transfer of new technologies.

If the desired advances involve improved components or subsystems, the Geothermal Energy Conversion Project seeks to motivate equipment suppliers to form project teams with dealers, developers, and system suppliers.

Cost considerations limit the current contribution of geothermal resources to the nation's energy mix. In many cases, however, the cost of power could be reduced and more resources exploited. An assessment of existing geothermal plants indicates that most of the easily accessible, higher-temperature geothermal resources have already been exploited. Therefore, the development of new resources will increasingly rely on the economic exploitation of liquid dominated, low- to moderate-temperature resources.

Since its inception in 1993, the geothermal program at NREL has worked closely with DOE, the DOE Golden Field Office, and the U.S. geothermal industry. During this short time, NREL has been able to demonstrate its expertise in conversion technology pertinent to geothermal energy, establishing important collaborative agreements with the U.S. industry such as those with the Pacific Gas and Electric Company for testing structured packing in direct-contact condensers, and with CalEnergy (previously Magma Operating Company) for field testing of protectively coated heat exchanger tubes.

In order to facilitate appropriate support of the geothermal industry's research, development, and demonstration needs by DOE, NREL has helped organize the Geothermal Power Organization, which is a new organization formed to provide industry-driven research objectives and guidance.

Workers installed a geothermal heat-pump system in a newly renovated building on the Georgia Tech campus in preparation for the 1996 Summer Olympic games in Atlanta. (Photo - Craig Miller Productions and DOE)

NREL's research is improving the viability of geothermal technology for near-term applications both in the United States and overseas. NREL is actively pursuing development of innovative binary cycles, advanced heat-rejection systems, field testing of advanced heat exchanger coatings, advanced direct-contact condenser technology, and laboratory testing of condensation of mixed working fluids. NREL is constructing a 600-kW test facility to test and evaluate advanced heat- rejection systems and other components relevant to binary geothermal cycles.

NREL has been able to demonstrate its expertise in conversion technology pertinent to geothermal energy.

Initiative: Enhanced Geothermal Energy Research and Development at NREL

Geothermal energy is an important domestic renewable energy resource with cost, reliability, and environmental advantages over conventional energy sources. Expansion of geothermal energy projects will broaden the energy base of our country in both the near term and long term. Currently, 2600 MW of installed capacity are available from 45 plants, located in California, Utah, and Nevada; worldwide, there are 5800 MW of installed capacity in 20 countries.

NREL proposes to enhance the geothermal research and development currently done at the Laboratory, to take advantage of NREL's expertise...

In the last two decades, EE has led a geothermal program which sponsors research that is strongly allied with industry and the national labs. Since 1970, EE has supported the development of technology for these plants with a financial commitment on the order of $1.3 billion for the entire geothermal program, including energy conversion, exploration, drilling, and reservoir technologies. It is estimated that industry and utilities together have spent about $5 billion for electric power generation programs alone. The technical accomplishments during this time have been impressive, and many DOE-sponsored advances have been incorporated into today's geothermal power plants.

Since its inception in 1993, the geothermal program at NREL has worked closely with EE and the industry. During this short time, NREL has demonstrated its expertise in conversion technology pertinent to geothermal energy. The Laboratory's research is improving the viability of geothermal technology for near-term applications both in the United States and overseas. NREL is actively pursuing development of innovative technology, including constructing a 600-kW test facility at the Laboratory for advanced heat rejection systems and other components.

NREL proposes to enhance the geothermal research and development currently done at the Laboratory, to take advantage of NREL's expertise in heat transfer, engineering, analysis, field program management, and excellent relationships with other DOE laboratories and the geothermal industry. NREL will help DOE develop advanced technologies and foster industry partnerships to help geothermal energy achieve full competitive status in domestic markets, and help the U.S. industry maintain leadership in international markets.

Since its inception in 1993, the geothermal program at NREL has worked closely with EE and the industry.

The enhanced NREL geothermal program will focus on several major objectives:

- Improve the economic viability of the geothermal energy conversion systems by proper utilization of the geothermal resources in environmentally friendly power plants

- Reduce the cost of geothermal plants by developing advanced and innovative energy conversion technologies with improved conversion efficiency
- Develop and demonstrate the long-term potential of geothermal technology through utilization of low temperature resources and heat mining
- Reduce the cost of electricity production from geothermal resources by developing new and innovative technologies that address operation and maintenance issues
- Help the geothermal industry better understand the international and domestic market challenges by developing new analytical tools and resource databases
- Provide technical guidance to EE in establishing a strong research strategy, assessing the status of existing geothermal energy conversion technologies, and address manufacturing- and market-related issues
- Support the U.S. industry to be more competitive in international markets by helping them to resolve technical problems as they adopt new technologies

Superconductivity

Superconductivity provides the ability to carry electricity with essentially no resistive losses at high transport currents. The discovery in 1986 of high-temperature superconductors (HTS) offers the potential for electric power devices that are more efficient, smaller in size and weight, cheaper to manufacture, and offer performance advantages over their conventional counterparts.

HTS power devices have the potential to save nearly 1 quad of energy annually due to combined savings in transmission and distribution losses and motor and generator losses; more than $1 billion per year could be saved due to reduced energy consumption. In addition, the use of high efficiency (>90%), large-scale electricity storage using superconducting components and superconducting current-limiters could help the utility industry save several billions of dollars per year by eliminating industry productivity losses due to power interruptions and providing more efficient use of the utility network, which would defer the need to upgrade and install new generation, transmission, and distribution equipment.

NREL's superconductivity program focuses on the development of a practical wire or tape using thallium-oxide superconductors.

During the past few years the development of HTS has been pursued for a wide range of electric power applications with emphasis on motors and generators, underground transmission cables, and fault-current limiters for distribution substations. The major technical challenge is the fabrication of a low-cost practical wire or tape with the required performance to carry sufficient current at technologically useful magnetic fields at a temperature close to that of liquid nitrogen.

The primary focus for the NREL superconductivity program has been the development of a practical wire or tape using the thallium-oxide superconductors. The thallium-oxide superconductors provide inexpensive processing approaches and benefit from characteristics which are competitive with other key oxide superconductors such as yttrium-based compounds.

NREL uses its own electrodeposition approach to directly produce high-quality thick films and submicron powders that can be used for the spray preparation of thick films. NREL is currently working with Oak Ridge National Laboratory and Los Alamos National Laboratory to apply our unique processing approaches to the demonstration of a biaxially textured thick-film tape of the single-layer thallium compound on a flexible substrate.

NREL will concentrate on the demonstration and commercial scale-up of the single–layer thallium compounds using thick-film processing methods such as electrodeposition and spray techniques.

NREL is also providing technical support to DOE for the Superconductivity Partnership Initiative [SPI], which provides financial assistance to industry teams for the design and development of HTS components for electric power applications.

During the next 5 years NREL will continue to develop thallium-oxide superconductors in a wire or tape configuration suitable for application to power–related components. NREL will concentrate on the demonstration and commercial scale-up of the single–layer thallium compounds using thick-film processing methods such as electrodeposition and spray techniques. The successful development of a long-length, biaxially textured thallium tape will provide a cost-effective HTS conductor with technologically acceptable performance. NREL will also continue to provide technical support for the DOE/SPI and help DOE monitor the SPI programs. Lastly, NREL will work closely with the renewable energy areas such as wind and photovoltaics to develop a renewables-oriented energy storage program that will facilitate the integration of renewables into grid and stand-alone installations.

Resource Assessment

Resource assessment is the characterization of the magnitude, distribution, and certainty of the energy resource available to solar, wind, biomass, geothermal, and hydro resources. Resource information is used to predict the performance of renewable energy technologies, and to indicate where it is most suitable to install these technologies.

NREL's resource assessment activities produce objective, high quality data and information for use by designers, planners and developers of renewable energy technologies.

Assessment activities have been under way at private institutions and national laboratories since the early 1970s, with the major emphasis placed on analyzing existing data sources (such as solar and wind data collected by the National Weather Service), and developing models to estimate resources where no data exist. Products from these activities are used extensively by government planning entities, utilities, industry, and energy developers.

Currently, core research in solar, wind, biomass, and geothermal resource assessments is supported by the technology programs, but is managed under a single organization at NREL.

A proper assessment of renewable energy resources can reduce the evaluation time associated with the development of specific sites for renewable energy technologies. When performed in a common format, assessments of different energy resources can be used to guide planners and developers in evaluating the marketability of various technologies, analyzing trade-offs among the technologies, and studying hybrid (such as village power) applications.

Reducing uncertainty in resource information helps condition markets for large-scale deployment, and reduces the risks associated with the expected performance of the technologies, and therefore in the financial investment in these technologies.

NREL's resource assessment activities produce objective, high quality data and information for use by designers, planners and developers of renewable energy technologies. NREL's products assure that the most informed decisions concerning the applications of those technologies can be made. The information is made readily available through a variety of ways, including a worldwide web site known as the Renewable Resource Data Center.

NREL develops and offers renewable energy resource maps, such as this solar radiation data grid for the southwestern United States in July. (Photo - Gene Maxwell, NREL)

Because of NREL's broad focus on all renewable technologies, this web site contains data for several different technologies, both for domestic and for international applications. This data base includes resource information made available from various research organizations, and is being organized and displayed using tools such as Geographic Information Systems.

Currently, core research in solar, wind, biomass, and geothermal resource assessments is supported by the technology programs, but is managed under a single organization at NREL to ensure that the best data quality assessment and reporting procedures are used for each resource category.

The web site will continue to serve as a principle mechanism for making these data and products available to the general public. Nevertheless, other outreach activities, including publications and training programs, will continue to broaden the capacity for the user to have access to and interpret the data and products that come out of this activity. In the future, an initiative will be launched to create a single budget authority to support cross-cutting resource assessment activities, thereby ensuring that critical research results are made available to our customers in a timely and useable format.